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Migration of Precocious Male Hatchery Chinook Salmon in the Umatilla River, Oregon

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Abstract.—Between 1993 and 2000, precocious yearling males of hatchery-produced fall and spring chinook salmon *Oncorhynchus tshawytscha* composed 3.6–82.1% of chinook salmon runs to the Umatilla River, Oregon. These yearling males are smaller than typical jack salmon, which spend a full winter in the ocean, and are commonly referred to as ''minijacks.'' Minijack fall chinook salmon are characterized by enlarged testes and an increased gonadosomatic index. Our goal was to determine if minijacks migrated to saltwater between the time they are released from the hatchery and the time they return to the Umatilla River, a period of 4–6 months. During 1999–2000, we collected otoliths from an adult male fall chinook salmon, 12 spring chinook salmon minijacks, and 10 fall chinook salmon minijacks. We measured strontium : calcium (Sr:Ca) ratios from the age-1 annulus to the edge of the otolith to determine whether these fish had migrated to the ocean. The Sr:Ca ratios increased from low values near the age-1 annulus, similar to ratios expected from freshwaters, to higher values near the edge of the otolith. The Sr:Ca ratios increased to levels similar to ratios expected in saltwater, indicating that these fish had migrated to saltwater before returning to the Umatilla River. Analysis of published water chemistry data from the Columbia and Snake rivers and rearing experiments in the main-stem Columbia River confirmed that high Sr:Ca ratios measured in otoliths were not the result of high strontium levels encountered in the freshwater environment. Previously assumed to remain within freshwater and near the point of release, our results suggest these minijack salmon migrated at least 800 km and past three hydroelectric dams to reach saltwater and return to the Umatilla River.

Chinook salmon *Oncorhynchus tshawytscha* can be classified broadly into two distinct life history types (Healey 1991). Stream-type, or spring chinook salmon, typically spend one or more years in freshwater before migrating to the ocean, whereas ocean-type, or fall chinook salmon, migrate to the ocean during their first year of life (Healey 1991). In addition to differences in the duration of juvenile freshwater residence, spring and fall chinook salmon exhibit differences in age at maturity and age structure of fish on the spawning grounds. Jacks, or males that mature at a younger age than the youngest females, typically return to spawn after one winter in the ocean and are common in many wild and hatchery populations of both spring and fall chinook salmon (Rutter 1902; Rich 1920; Healey 1991). In spring chinook salmon populations, male parr may mature without migrating to the ocean (Rich 1920; Gebhards 1960; Reimers and Concannon 1977; Taylor 1989; Mullan et al. 1992). In wild populations, the frequency of mature male parr within the juvenile population ranged from 1% to 2.6% in Columbia River tributaries (Gebhards 1960; Mullan et al. 1992), 10% to 12% in the McCloud River, California (Rich 1920), and up to 29% in a New Zealand population (Flain 1970). Although not observed in wild populations, precocious mature male parr are observed in hatchery populations of fall chinook salmon (Unwin et al. 1999). Precocious maturation is considered an undesirable outcome in hatchery operations because it may result in decreased returns of mature adult males (Taylor 1989; Clarke and Blackburn 1994).

A third form of precocious male chinook salmon has been observed in hatchery populations in the Columbia River basin in Oregon and Washington. In the Umatilla River, Oregon, some yearling releases of fall chinook salmon and spring chinook salmon return within only 4–7 months of release as precocious males that are less than 380 and 300 mm, respectively. Referred to as ''minijacks,'' they are smaller than typical jacks that have spent a winter in the ocean and are nearly twice the size

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of naturally produced mature male parr. Minijack returns have also been described from other Columbia River hatcheries and traps. Between 1990 to 1994, minijack returns to the Lyons Ferry Fish Hatchery on the Snake River, Washington, ranged from 102 to 377 (Mendel et al. 1996). Thomas et al. (1969) observed eight yearling male fall chinook salmon (approximately 350 mm total length) returning to the Leavenworth National Fish Hatchery on the Wenatchee River, an upper Columbia River tributary. From scale pattern analyses showing accelerated growth patterns inferred to represent ocean growth, Thomas et al. (1969) suggested that these fish migrated to the ocean. Whether minijacks migrate to the ocean or remain within reservoirs in the Columbia River is unknown. To better understand the conditions that promote development of minijacks, more information is needed to assess the extent of migration and environmental conditions encountered by fish returning as minijacks.

The chemical composition of otoliths can describe migration in anadromous fishes, specifically the ratio of strontium and calcium (Kalish 1990; Secor 1992; Limburg 1995; Radtke 1995; Secor and Rooker 2000; Volk et al. 2000). Strontium has binding characteristics similar to calcium (same valence and similar ionic radius) and is substituted for calcium in the calcium carbonate matrix of the otolith at levels reflecting the ratio of strontium to calcium in the environment (Kalish 1990). The Sr:Ca ratios are generally greater in seawater than freshwater, and therefore, analysis of Sr:Ca ratios across the otolith of a fish can identify growth occurring in freshwater versus saltwater. Transects across the otolith of anadromous salmonids are typically characterized by low Sr:Ca ratios corresponding to growth within freshwaters followed by increased Sr:Ca ratios associated with growth in the marine environment (Kalish 1990; Radtke 1995). As a result, transects of otolith strontium or Sr:Ca ratios are becoming a common tool to reconstruct the chronology of marine migrations and identify migratory subgroups (e.g., Babaluk et al. 1997; Kafemann et al. 2000; Howland et al. 2001). Because some freshwaters are naturally high in strontium, water chemistry must be analyzed in studies relying on Sr:Ca analysis to infer migration (Rieman et al. 1994).

Our objective was to determine whether minijack chinook salmon returning to the Umatilla River had migrated to saltwater based on analysis of otolith Sr:Ca ratios. To first confirm that analysis of otolith Sr:Ca ratios is appropriate for inferring fresh and saltwater residence of fish from the Umatilla River, we examined published water chemistry data to compare ambient Sr:Ca in the Columbia and Snake rivers adjacent to the mouth of the Umatilla River and at the upstream extent of the Columbia River estuary. We also held a test group of fish within the Columbia River to determine expected otolith Sr:Ca ratios for fish within the Columbia River. Finally, we measured Sr:Ca ratios in otoliths from minijack chinook salmon returning to the Umatilla River. Given the long distance (440 km) and difficulty of passage due to hydroelectric dams, we expected that Sr:Ca ratios between the first annulus and edge of the otolith would be low and indicative of only freshwater residence.

Methods

Study site.—Chinook salmon were extirpated from the Umatilla River, Oregon, by 1963. Reintroduction of fall and spring chinook salmon, from other Columbia River hatchery stocks, began in 1983 and 1986, respectively. Production goals for fall chinook salmon juveniles, which are released as yearlings at 16–17 months after fertilization, have been 100–400 thousand releases per year. Goals for spring chinook salmon, which are released as yearlings at 20 months after fertilization, have been 600 thousand releases per year. All chinook salmon returning to the Umatilla River are monitored at a trap at Three Miles Falls Dam (TMFD; Figure 1). Since 1993, coded-wire-tagging of hatchery-produced chinook salmon in the Umatilla River has allowed detailed monitoring and identification of minijack returns to TMFD.

Description of minijacks.—Counts of fish returning to the Umatilla River were conducted at TMFD fish trapping facilities during 1993–1999 (Figure 1). Hatchery fish were initially identified by fin-clips, and coded wire tags (CWT) were read to identify fish to hatchery and rearing groups. Precocious males (minijacks) were identified by sexual maturation (as indicated by enlarged testes) at sizes under 400 mm fork length. Spring and fall chinook salmon were initially identified based on timing of run and then confirmed based on CWT identification. We focused our efforts on the description of fall chinook minijacks because precocious maturation is most uncommon in this life history form and the proportion of fall chinook minijacks is of a great concern in the Umatilla River. We used ordinary least-squares regression to test the relationship between total release of yearling smolts and total return of minijacks by

FIGURE 1.—Location of Umatilla River, U.S. Geological Survey water chemistry sampling locations at Vernita Bridge (1), Snake River at Burbank (2), and the Columbia River at Beaver (3).

brood year. In 1999, we weighed total body weight and weight of gonads from 60 fall chinook salmon yearlings (haphazard sample) that were sacrificed at release to compare the gonadosomatic index (GI) with minijacks, where GI = (gonad weight/body weight) × 100.

Water chemistry and otolith validation.—Because determination of freshwater and saltwater growth based on otolith Sr:Ca ratios can be confounded by high Sr:Ca ratios in some freshwaters (Rieman et al. 1994), we examined available data for Sr:Ca in the Columbia and Snake rivers. We used previously published data from the U.S. Geological Survey National Stream Quality Accounting Network (Kelly et al. 2001) available on the World Wide Web (http://water.usgs.gov/nasqan) to determine Sr:Ca ratios in the Columbia River and adjacent Snake River. We calculated Sr:Ca ratios (mmol/mol) for October 1995 through August 1999 for three locations (Figure 1): Columbia River at Beaver (USGS 14246900), Columbia River at Vernita Bridge (USGS 12472900) and Snake River at Burbank (USGS 13353200). The Sr:Ca ratios were plotted over time to determine seasonal variation and to compare with saltwater values. We assumed ocean Sr:Ca ratios of 8.6–8.74 mmol/mol, based on data of Bruland (1983) and Nozaki (1997).

To test the relation between otolith Sr:Ca ratios and ambient Sr:Ca ratios in the Umatilla Hatchery and Columbia River waters, two groups of juvenile chinook salmon were held in a live-cage in the Columbia River just down stream of McNary Dam (Figure 1). The first group consisted of five juvenile fall chinook salmon that were held in the Columbia River from 26 June to 10 July 2000. The second group consisted of 10 juvenile spring chinook salmon held in the same location from 19 January to 2 February 2001. Just before release into the live-cage, these fish were immersed in a solution of 50 mg/L alizarin complexone for 4 h to mark the beginning of the experimental trial on the otolith (Thomas et al. 1995; Beckman and Schulz 1996).

Otolith collection.—Sagittal otoliths were collected from 12 minijack spring chinook salmon (<300 mm fork length) returning to TMFD during 9–12 July 1999 and 10 minijack fall chinook salmon (<380 mm) returning between 28 September and 25 October 1999. Sagittal otoliths from one adult male chinook salmon (866 mm fork length), assumed to have migrated to saltwater, were collected for comparison. Otoliths were removed from all live-cage-held fish as well. All otoliths were removed immediately, cleaned, and stored in dry vials until analysis.

Otolith preparation and analysis.—One sagittal otolith from each fish was mounted with heated Crystal Bond 509, sulcus-side-down, on a microscope cover slip attached on one edge to a standard microscope slide. The otolith was then ground with 1,200-grit sandpaper in the sagittal plane to the level of the nucleus. The mounting medium was heated and the otolith turned sulcus side-up. The otolith was then ground with 1,200-grit and 2,000-grit sandpaper in the sagittal plane to the level of the nucleus and polished with a slurry of 0.05-μm alumina paste. The cover slip was then cut with a scribe so that several prepared otoliths could be mounted on a petrographic slide for electron microprobe analysis. The slide containing several otoliths was rinsed with deionized water, air-dried, and coated with a 400-Å carbon layer. Elemental analysis was conducted with a Cameca SX-50 wavelength dispersive electron microprobe. A 15-kV, 50-nA, 7-μm-diameter beam was used for all analyses. Strontiantite and calcite were used as standards for strontium and calcium, respectively. Each element was analyzed simultaneously, and a counting time of 40 s was used to maximize precision (Toole and Nielsen 1992). Strontium was measured using the TAP crystal, and calcium was measured using the PET crystal. We report Sr:Ca ratios as atomic ratios.

On otoliths of juveniles held in the Columbia

TABLE 1.—Releases of yearling hatchery-reared fall chinook salmon and returns of precocious male minijacks (<381 mm), Umatilla River, Oregon.

Brood year	Number released	Minijack returns	Percent of total return
1991	134,800	15	3.6
1992	283,500	368	24.8
1993	227,000	338	27.5
1994	564,400	606	45.5
1995	519,900	189	25.2
1996	436,000	261	34.3
1997	449,600	152	14.8
1998	469,800	4,948	82.1

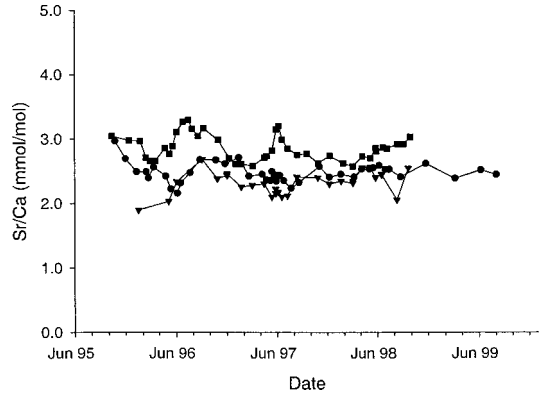

FIGURE 2.—Ambient Sr:Ca ratios (mmol/mol) in the Columbia River at Beaver (circles), Columbia River at Vernita (triangles), and Snake River at Burbank (squares). Years are designated by their last two digits.

River live cage, otolith regions were defined as hatchery and Columbia River using the alizarin complexone mark as the boundary separating otolith growth that occurred in the two environments. The Sr:Ca ratios were measured in an equal number of points within each region for each fish. To account for lack of independence among microchemical samples collected within individual otoliths (same fish), we used repeated-measures analysis of variance (ANOVA) to compare Sr:Ca ratios in hatchery and river growth regions; we considered each fish as the independent statistical unit (Chambers and Miller 1995).

To infer extent of migration exhibited by minijacks, Sr:Ca ratios were measured along otolith transects beginning at the age-1 annulus and continuing to the edge of the otolith. Because juveniles are released in the spring, formation of the age-1 annulus was assumed to occur in the months preceding release and served as a natural mark while the fish were still in captivity. Transects of otolith Sr:Ca ratios from the age-1 annulus to the edge of the otolith were plotted and compared to ratios observed in experimental fish (hatchery and Columbia River regions), those in the saltwater growth region of the single adult and with expected Sr:Ca ratios from other studies. Minijack salmon were classified as freshwater residents if plots of Sr:Ca ratios between the age-1 annulus and the edge of the otolith were flat and similar to that measured in the hatchery growth zone. Conversely, minijacks were classified as saltwater migrants if the Sr:Ca ratios between the age-1 annulus and the edge of the otolith peaked to levels observed in the saltwater growth region of the adult otolith.

Results

Minijack Returns

Since 1993 (brood year 1991), returns of minijack fall chinook salmon to the Umatilla River ranged from a low of 15 to a high of 4,948 in 1998 (Table 1). The mean return (±SD) of minijacks to the Umatilla River during the ensuing 8-year period was 860 (SD = ±1,661) fish, but this statistic was strongly influenced by the 1998 datum. Excluding the 1998 return, the mean number of fall chinook returning as minijacks was 276 ± 188 fish. During this period, the percentage of smolts released that returned as minijacks ranged from 0.01% to 1.05% (mean = 0.20%). The total return of fall minijacks was not correlated to total release of yearling smolts ($r^2 = 0.21$, df = 6, $P = 0.25$). The GI of 60 yearling chinook salmon at release (150 mm fork length) was under 1%. The mean GI of 26 minijack fall chinook salmon was 6.63 ± 0.91%. The mean length of fall chinook salmon minijacks collected for otolith analysis was 346 ±26 mm and for spring fish was 263 ± 17 mm.

Water Chemistry

The Sr:Ca ratios of water at the three USGS sampling locations ranged from 1.9 to 3.3 mmol/mol (Figure 2). The highest Sr:Ca occurred in the Snake River and the lowest in the Columbia River at Vernita Bridge, which is upstream of the confluence of the Snake and Columbia rivers. The Sr:Ca ratios in the Columbia River at Beaver, which is considered the beginning of the Columbia River estuary, ranged from 2.1 to 3.3 mmol/mol (Figure 2). At 8.6–8.74 mmol/mol, Sr:Ca ratios in saltwater are 2.6–4.5 times higher than those observed at the three locations within the Columbia and Snake rivers.

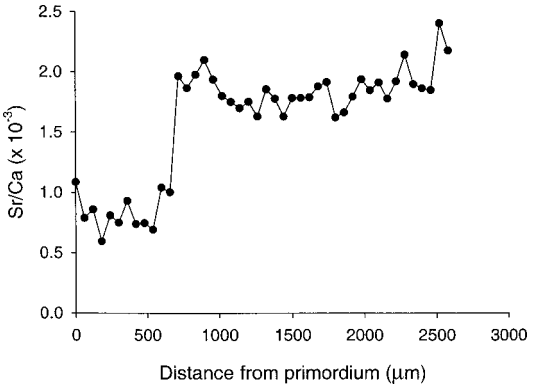

FIGURE 3.—Transect of otolith Sr:Ca ratios beginning in a single primordium and concluding at the edge of the otolith of an adult male fall chinook salmon, Umatilla River, Oregon.

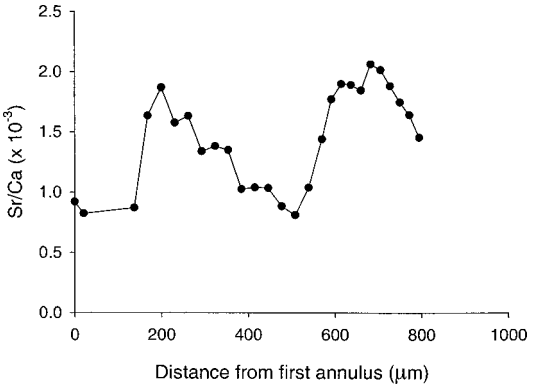

FIGURE 4.—Transect of otolith Sr:Ca ratios beginning at the age-1 annulus and concluding at the edge of the otolith of a minijack fall chinook salmon, Umatilla River, Oregon.

Otolith Microchemistry

The Sr:Ca ratios across a transect of points beginning in the primordia and concluding at the edge of the otolith of the adult male chinook salmon were similar to those of anadromous salmonids reported previously (e.g., Kalish 1990; Radtke 1995). Low Sr:Ca ratios (range 0.0006–0.0010) were measured in the freshwater growth region, and high Sr:Ca ratios (range 0.0016–0.0024) were measured in the ocean growth region of the otolith as identified based on banding patterns before microchemical analysis (Figure 3).

Otolith Sr:Ca ratios did not differ significantly between periods of hatchery growth and Columbia River growth for 15 young spring and fall chinook salmon (repeated-measures ANOVA: $F_{1,14} = 1.37$, $P = 0.26$). The mean Sr:Ca ratio within the hatchery growth region of the 15 young spring and fall chinook salmon was 0.00092 (SD = ±0.00015) and mean Sr:Ca ratio in the otolith representing the time that these juveniles were held in the Columbia River was 0.00076 ± 0.00014. Thus, water in the Umatilla or Columbia rivers probably would not result in high Sr:Ca ratios, as would be expected from otolith growth occurring in saltwater.

All minijacks were classified as saltwater migrants based on variation of Sr:Ca ratios along transects from the age-1 annulus to the edge of the otolith. The mean Sr:Ca ratio at the age-1 annulus was 0.00078 ± 0.0002 for spring chinook salmon minijacks ($N = 10$) and 0.00078 ± 0.0001 for fall fish ($N = 9$). Mean maximum Sr:Ca ratios between the age-1 annulus and edge of otolith was 0.00186 ± 0.0003 (range = 0.00130–0.00220) for spring fish ($N = 10$) and 0.00218 ± 0.0001 (range = 0.00202–0.00240) for fall fish ($N = 9$). Had minijacks remained in freshwater, Sr:Ca ratios probably would have remained within the range observed in the Columbia River growth region of the test fish held below McNary Dam. Maximum Sr:Ca ratios between the age-1 annulus and the edge of the otoliths were within the range of Sr:Ca ratios observed in the saltwater growth region of the adult. Duration of saltwater residence varied among minijacks. One fall minijack was characterized by two distinct peaks in Sr:Ca ratios, which suggests it had encountered saltwater twice before returning to the Umatilla River (Figure 4). The remaining minijacks were characterized a single peak in Sr:Ca ratios between the age-1 annulus and the edge of otolith, which suggests only one period of saltwater residence (Figure 5).

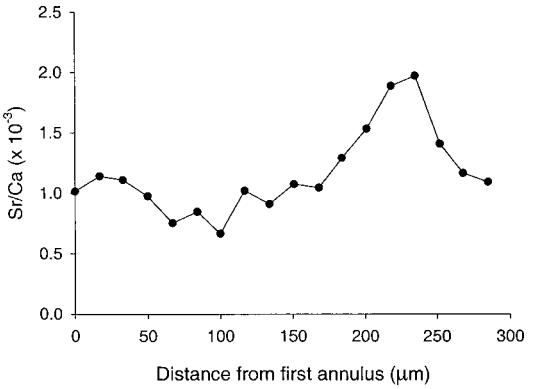

FIGURE 5.—Transect of otolith Sr:Ca ratios beginning at the age-1 annulus and concluding at the edge of the otolith of a minijack spring chinook salmon, Umatilla River, Oregon.

Discussion

Although we were only able to sample a small number of minijack chinook salmon returning to the Umatilla River, our results suggest that migration exhibited by these fish is much greater than anticipated. Given the distance and difficulty of migration past three mainstem Columbia River dams, these fish were previously assumed to have remained within the Columbia River near the confluence of the Umatilla River. Rather, within 4–7 months of release, the fish we examined appear to have migrated at least 400 km to the Columbia River estuary or beyond and then, returned at least 400 km to the Umatilla River.

Analysis of otolith microchemistry confirmed that minijack chinook salmon migrated to saltwater between the times they were released as smolts and subsequently recaptured. In this case, otoliths provided an archival tag-measuring correlates of salinity and, thus, provided a means to identify time spent in saltwater. Because this method is dependent on the assumption that freshwaters are low in Sr, we included analysis of ambient Sr:Ca in Columbia and Snake Rivers to ensure that the increased Sr:Ca ratios in otoliths were due to saltwater entry. Alternatively, these fish could have migrated to a location high in Sr:Ca. The Columbia and Snake Rivers are low in Sr:Ca relative to ocean levels and we know that this is true as far downstream as the USGS station at Beaver (Figure 1). Thus, we believe that the minijacks examined in this study migrated to a point downstream of that location.

In addition to environmental variation in ambient water chemistry, Sr:Ca ratios in otoliths can be influenced by crystal structure (Gauldie 1996; Brown and Severin 1999), maturation (Friedland et al. 1998), and temperature (Townsend et al. 1992). Typically, the calcium carbonate matrix in otoliths is deposited as aragonite but can also be deposited as vaterite or calcite (Gauldie 1993). Vaterite replacement of aragonite is characterized by extremely low levels of strontium substitution for calcium (Gauldie 1996; Brown and Severin 1999). As a result, we avoided measuring Sr:Ca ratios in otolith regions of vaterite, or we excluded otoliths with greater than 50% vaterite replacement. Many of the minijack samples analyzed in this study were characterized by vaterite replacements of 10–60%, based on visual examination.

Maturation has been shown to affect otolith Sr:Ca ratios in Atlantic salmon *Salmo salar*. Friedland et al. (1998) compared Sr:Ca ratios in immature and maturing Atlantic salmon caught at sea and found that the deposition of Sr:Ca was related to somatic growth and maturation. Further, they found distinct peaks of otolith Sr:Ca ratios just before Atlantic salmon entered freshwater to spawn. The difference in Sr:Ca ratios within the saltwater otolith growth region attributed to maturation by Friedland et al. (1998) was approximately 0.0004. The difference between minimum and maximum Sr:Ca ratios in the minijack chinook salmon in this study ranged from 0.006 to 0.0017, suggesting that these differences were due to shift in habitat (freshwater to saltwater), rather than maturation, assuming the maturation pathway in adult Atlantic salmon and Umatilla River chinook minijacks is similar. Like maturation, temperature has been shown to affect otolith Sr:Ca ratios (Townsend et al. 1992). Similar to maturation, the influence of temperature on otolith Sr:Ca ratios is likely to be much less than shifts in salinity (Campana 1999). Campana (1999), in a discussion of the relative role of temperature and salinity in determining otolith Sr:Ca ratios, suggests that a change of 15–30°C would be required to produce Sr:Ca ratio changes of the magnitude observed between freshwater and saltwater growth regions of otoliths. Campana (1999) also pointed out that temperature effects have only been observed when median temperatures are below 10°C. Therefore, difference between Sr:Ca ratios at the age-1 annulus and maximum Sr:Ca ratio measured between the age-1 annulus and edge of the otolith were not likely to be a result of temperature differences. Using the equation provided by Campana (1999) of each degree of rising temperature resulting in a 0.0001 decline in otolith Sr:Ca, a temperature drop of 8–17.5°C after release from the hatchery would be needed to produce the observed differences of Sr:Ca ratios between the age-1 annulus and maximum Sr:Ca ratios encountered after release.

Although only 0.01–1.05% of yearling releases returned as minijacks, they compose 3.6–82.1% of the total run of fall chinook salmon. The ecological and management implications of this undesirable life history form are not fully understood but include potential impacts on the age structure of fish spawning in the wild, overestimation of fall chinook salmon escapement, and decreased returns of adult chinook salmon (Taylor 1989; Clarke and Blackburn 1994).

Understanding the physiological state of these chinook salmon as they reach saltwater may help to elucidate the factors favoring precocial matu-

ration in fall and spring releases. Because smolting and early sexual maturation are mutually exclusive processes (Randall et al. 1987; Thorpe 1987), maturation as these fish reach saltwater may preclude smolting and migration to the ocean (Foote et al. 1991). Further work is needed to examine growth and smolting in Umatilla River hatchery chinook.

Hatchery practices that include increasing growth, resulting from overwintering in warmer-than-ambient water temperature and excessive artificial feeding, may trigger early maturation. Faster growth may lead to early sexual maturation in chinook salmon, leading to a completed life cycle in freshwater (Clarke and Blackburn 1994). The hatchery practice of releasing salmon smolts at larger-than-natural size to increase survival may increase precocial maturation (Mullan et al. 1992) and, hence, minijack production. Occurrence of minijacks may be exacerbated in fall chinook salmon because yearling releases are not commonly practiced and age-1 smolts are not observed in wild populations. Subyearling releases in the Umatilla River do not mature into minijacks. Unwin and Glova (1997) suspected that extended hatchery rearing of 8–12 months was partially responsible for early maturation in a chinook salmon population in New Zealand. They found that differences between fish of hatchery and wild origin were primarily related to hatchery rearing practices, but there was also a general decline in age at maturity of wild males.

The potential effects of chinook salmon minijacks spawning in the wild are unknown. If minijack production is related to inherited traits, such as growth or age at maturity, spawning of minijack salmon in the wild may lead to changes in the age structure or growth characteristics of wild fall chinook salmon. Such a shift would be contrary to the goal of reintroducing a naturally sustaining population of fall chinook salmon in the Umatilla River. As a result, research concerning the magnitude and reproductive success of minijack spawning is needed to guide management of chinook salmon populations in the Umatilla River. Minijacks are not included in hatchery broodstock, but we do not know if they spawn naturally in the Umatilla River. Minijacks have been observed in areas of spawning salmon (P. Kisner, Confederated Tribes of the Umatilla Indian Reservation, personal communication). Limiting escapement of minijacks and, hence, spawning by minijacks can be achieved by collecting them at the TMFD fish trap and by increasing their harvests by sport anglers. Further research is needed concerning physiological, behavioral, and genetic factors that promote or induce maturation in yearling releases of chinook salmon and to find methods of preventing the formation of minijacks in the Umatilla River.

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